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Foley

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(54) **APPARATUS AND METHOD TO CONTROL SENSOR POSITION IN LIMITED ACCESS AREAS WITHIN A NUCLEAR REACTOR**

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G21C 17/003 (2006.01)
(Continued)

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CPC ***G21C 19/20*** (2013.01); ***G01N 29/225*** (2013.01); ***G01N 29/265*** (2013.01); ***G21C 17/003*** (2013.01); ***G21C 17/013*** (2013.01); ***G21C 19/207*** (2013.01)

(58) **Field of Classification Search**
CPC ... G21C 19/20; G21C 17/003; G21C 17/013
USPC 376/245, 249, 260
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,213,732 A * 7/1980 Cooper 376/260
5,215,706 A * 6/1993 Cross et al. 376/245
(Continued)

FOREIGN PATENT DOCUMENTS

JP H07110320 A 4/1995
JP 2619020 B2 6/1997
(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion of the International Searching Authority for PCT/US2013/063633 dated Jul. 10, 2014 (Forms PCT/ISA/220, PCT/ISA/210, PCT/ISA/237).
(Continued)

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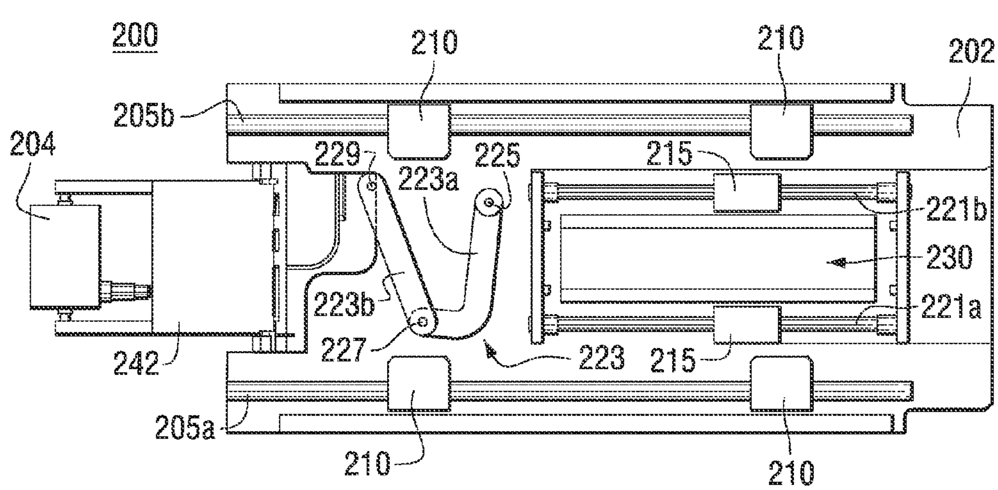
(57) **ABSTRACT**

This invention concerns robotic systems and is specifically concerned with an improved apparatus and method for remotely positioning a sensor, such as an ultrasonic probe, in limited access areas within a nuclear reactor. The apparatus includes a bottom frame and a top cover which is substantially aligned with and positioned above the bottom frame. A sensor is connected to the top cover and linear rails are connected to the bottom frame in a parallel relationship. There is a mechanism movably connected to the first and second linear rails in order to allow horizontal travel of the top cover. Further, there is at least one cable connected to the sensor and a power source, signal source or receiver.

7 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

G21C 17/013	(2006.01)
G01N 29/22	(2006.01)
G01N 29/265	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,444,746	A *	8/1995	Okamoto et al.	376/245
5,544,206	A *	8/1996	Brooks et al.	376/245
5,784,425	A	7/1998	Morlan	
5,955,852	A *	9/1999	Jentsch	318/282
6,058,153	A *	5/2000	Kurosawa et al.	376/260
6,145,583	A *	11/2000	Gay et al.	376/245
7,308,069	B2 *	12/2007	Legard et al.	376/245
8,046,959	B2 *	11/2011	Stoetzer et al.	52/116
9,117,554	B2 *	8/2015	Vigliano	G21C 17/003 376/249
2007/0146480	A1	6/2007	Judge, Jr. et al.	

FOREIGN PATENT DOCUMENTS

JP	H09211182 A	8/1997
JP	2006061976 A	3/2006

OTHER PUBLICATIONS

International Preliminary Report on patentability for PCT/US2013/063633 dated Apr. 23, 2015 (Forms PCT/IB/326, PCT/IB/373, PCT/ISA/237).

* cited by examiner

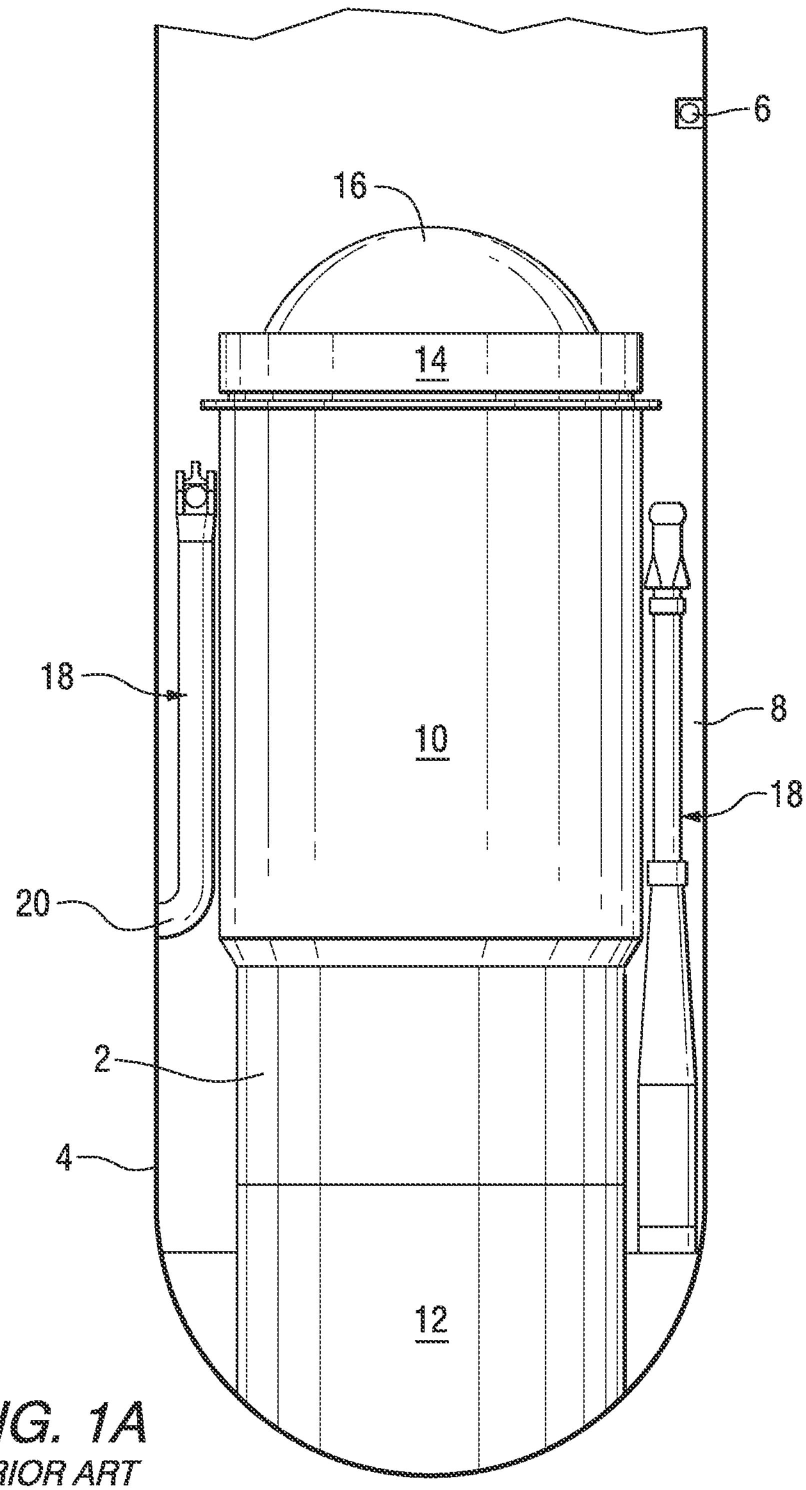


FIG. 1A
PRIOR ART

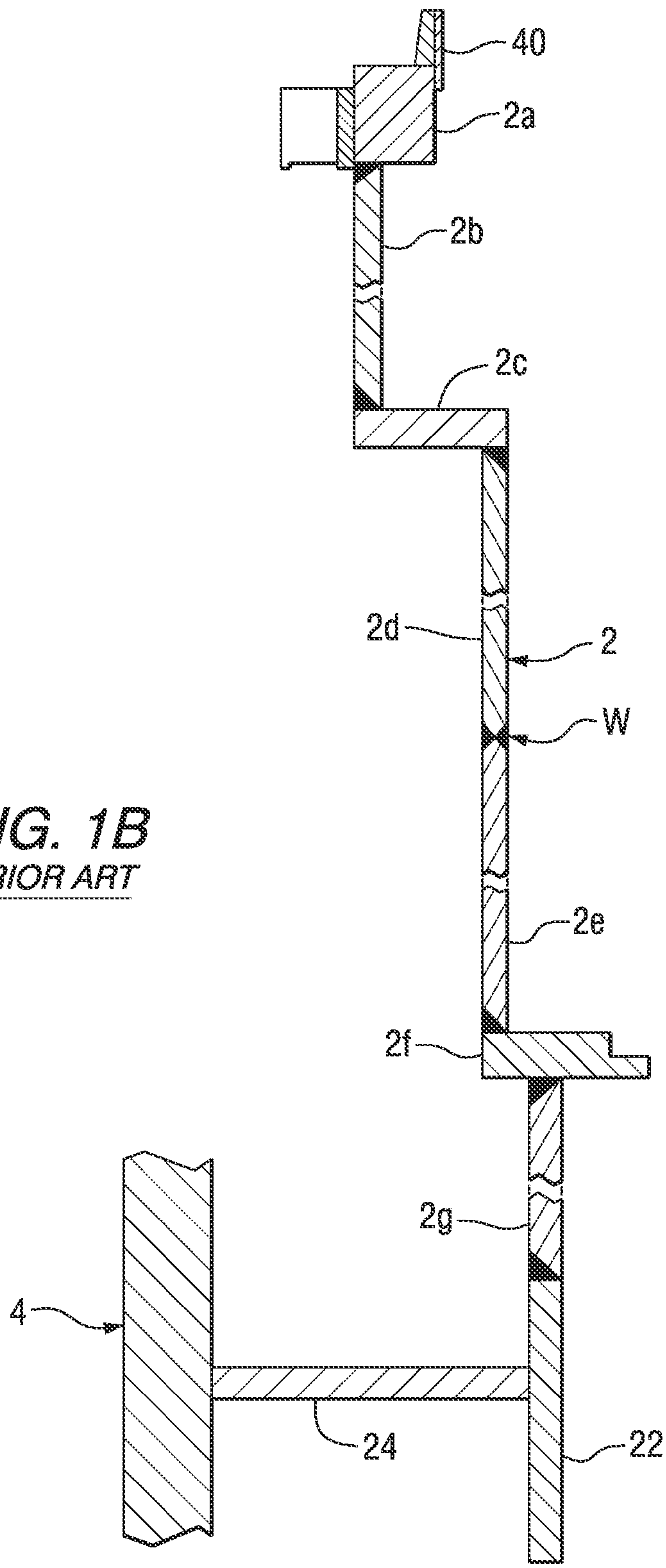


FIG. 1B
PRIOR ART

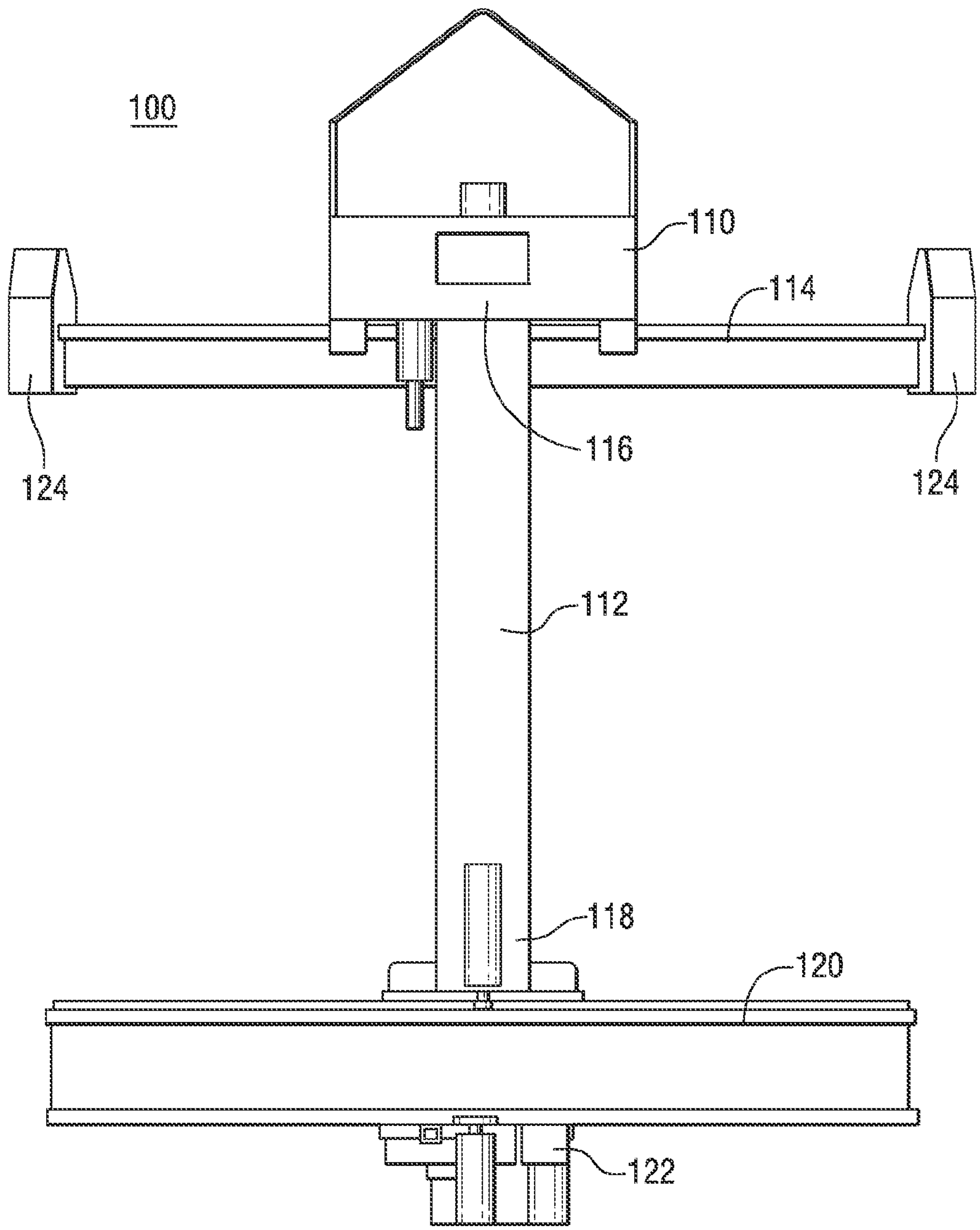


FIG. 2

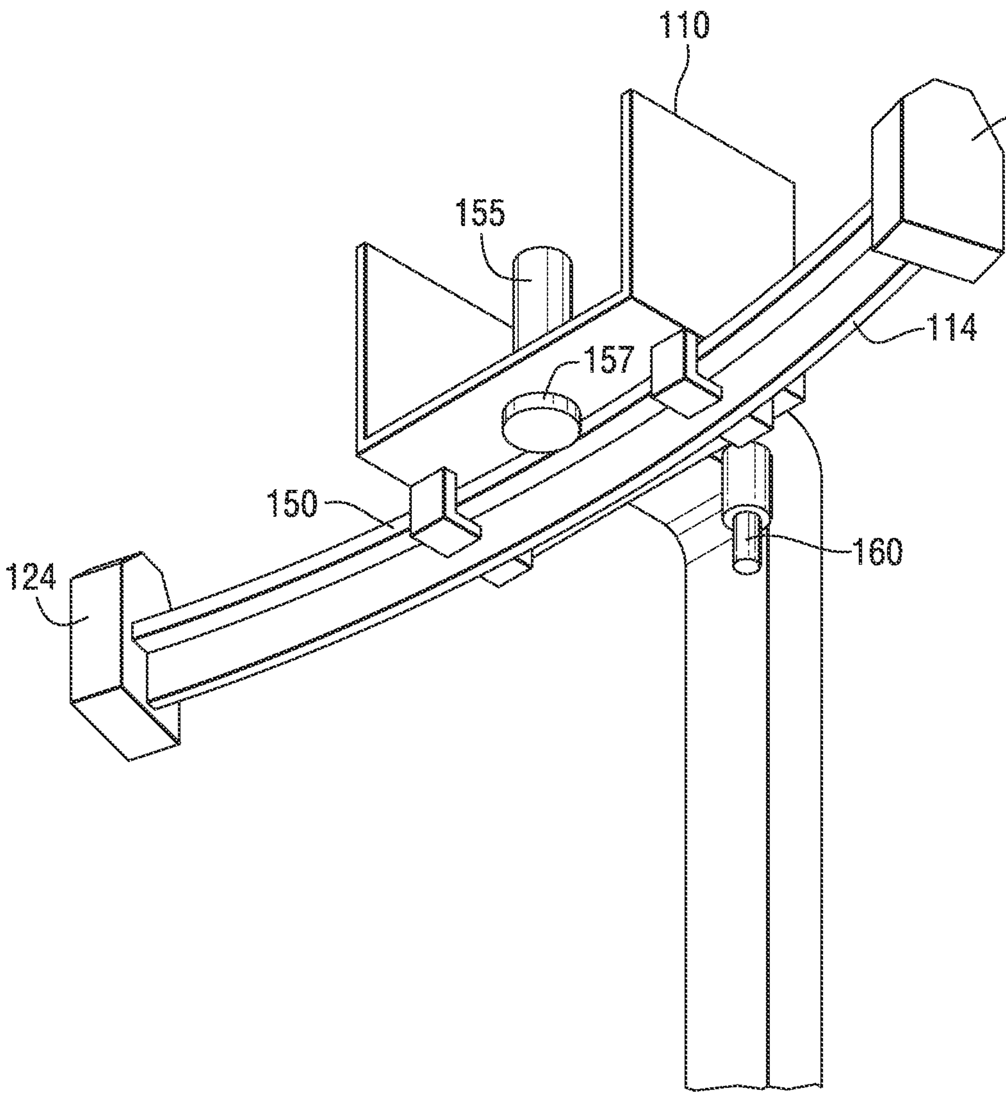


FIG. 3

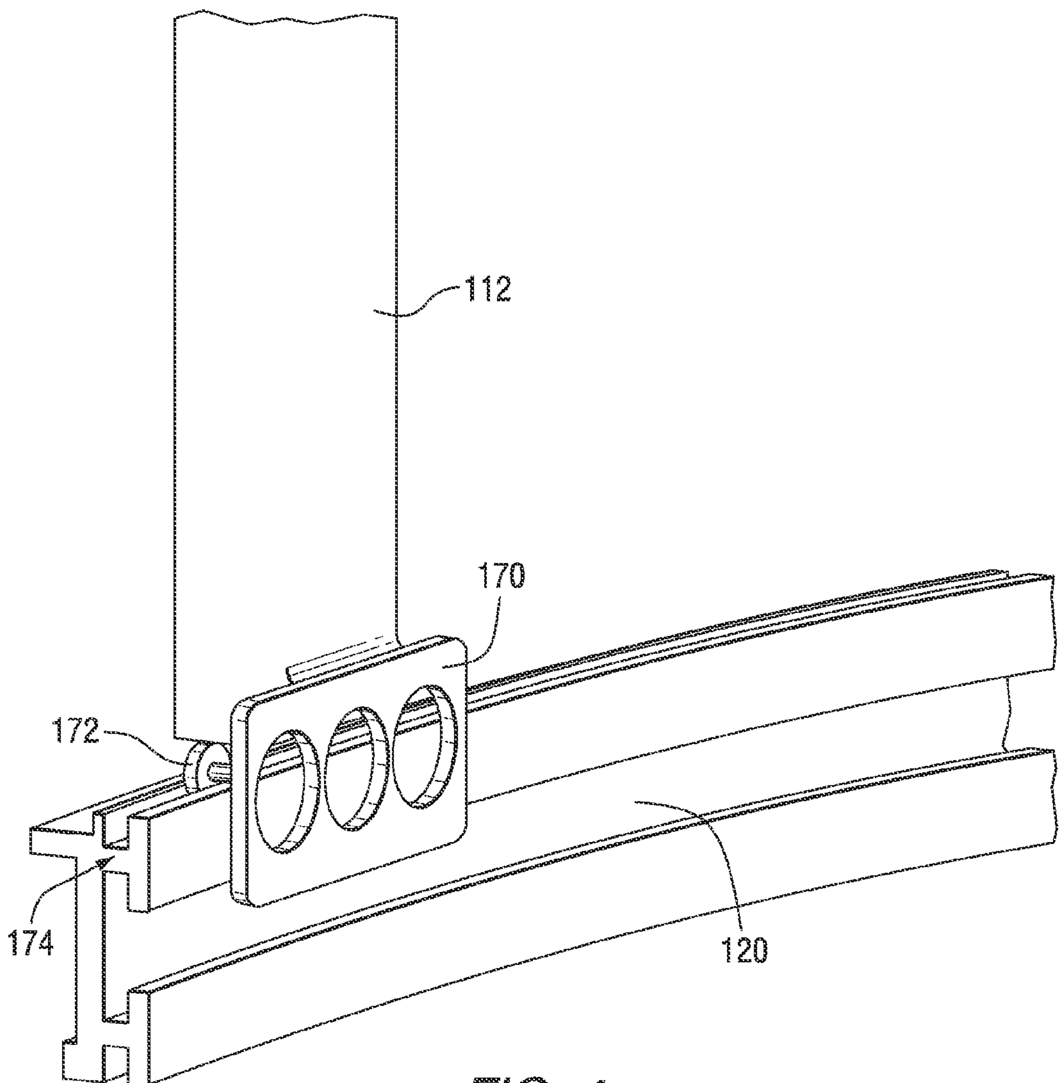


FIG. 4

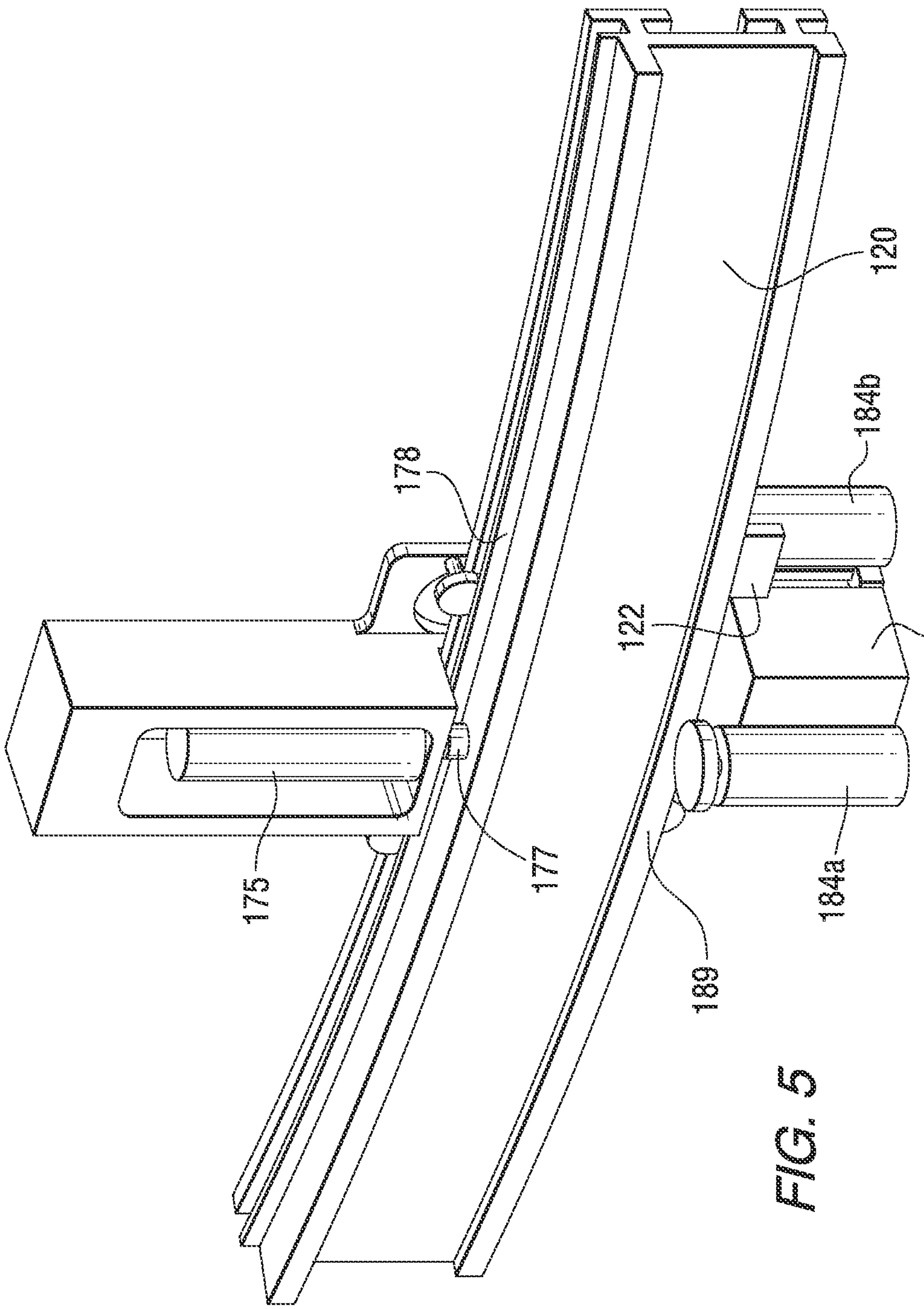


FIG. 5

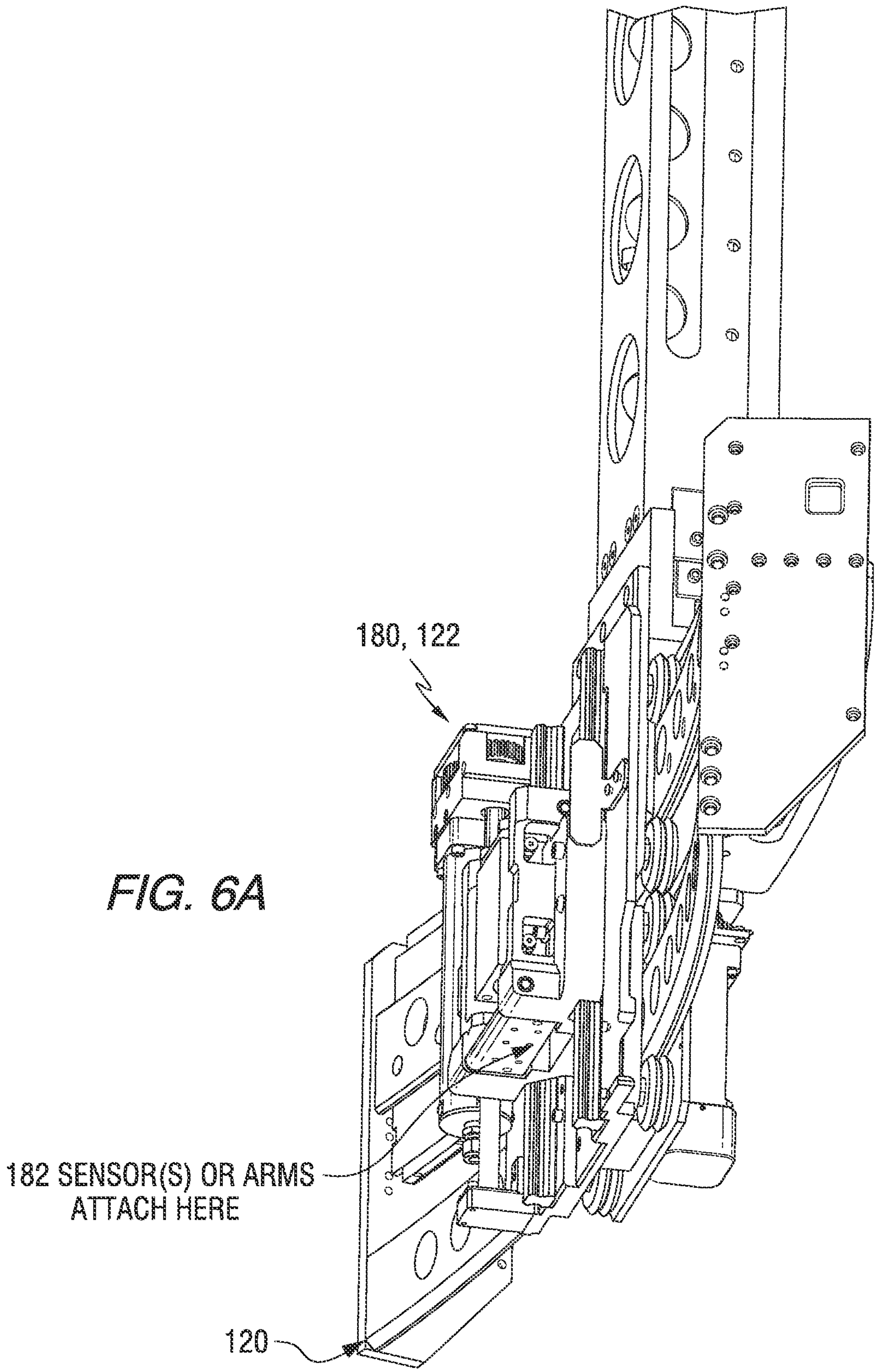


FIG. 6A

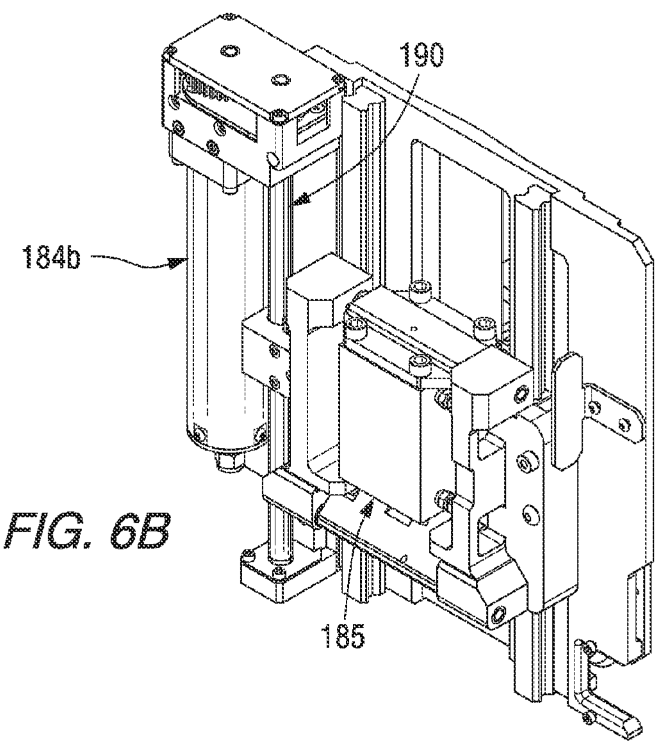


FIG. 6B

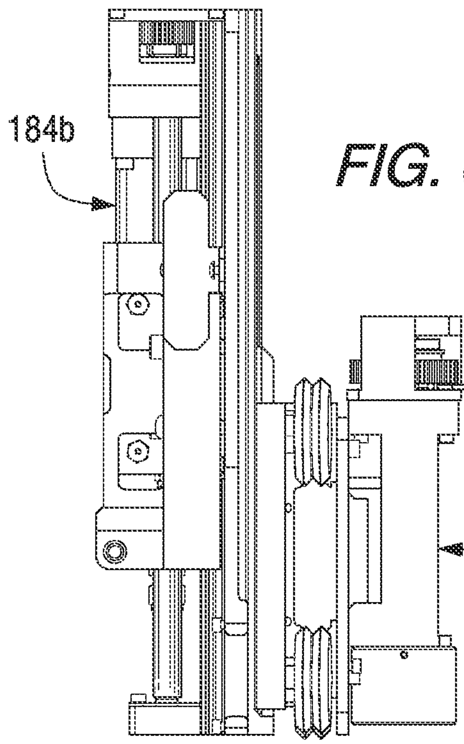


FIG. 6C

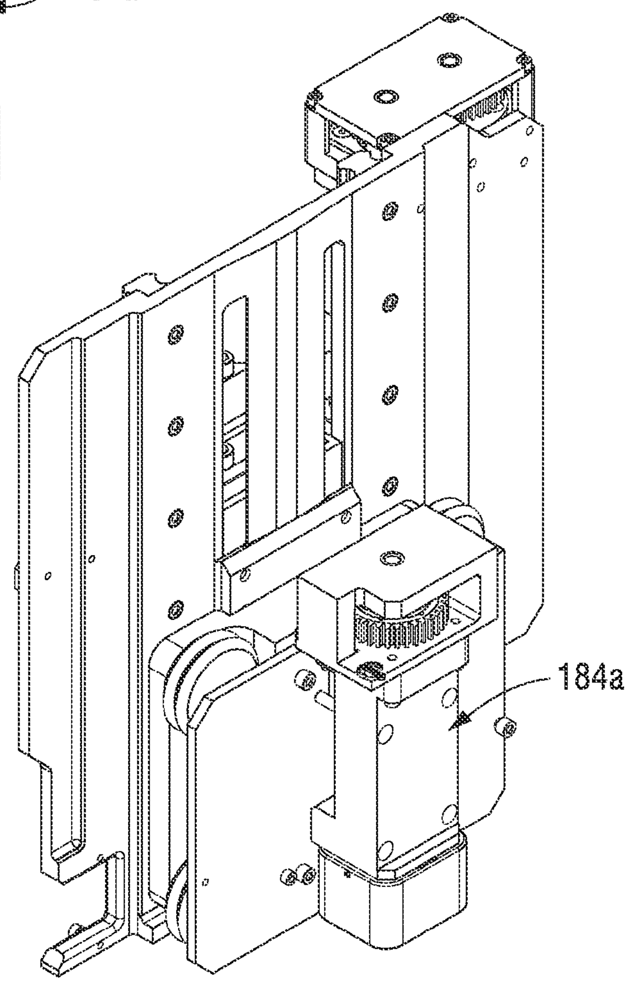
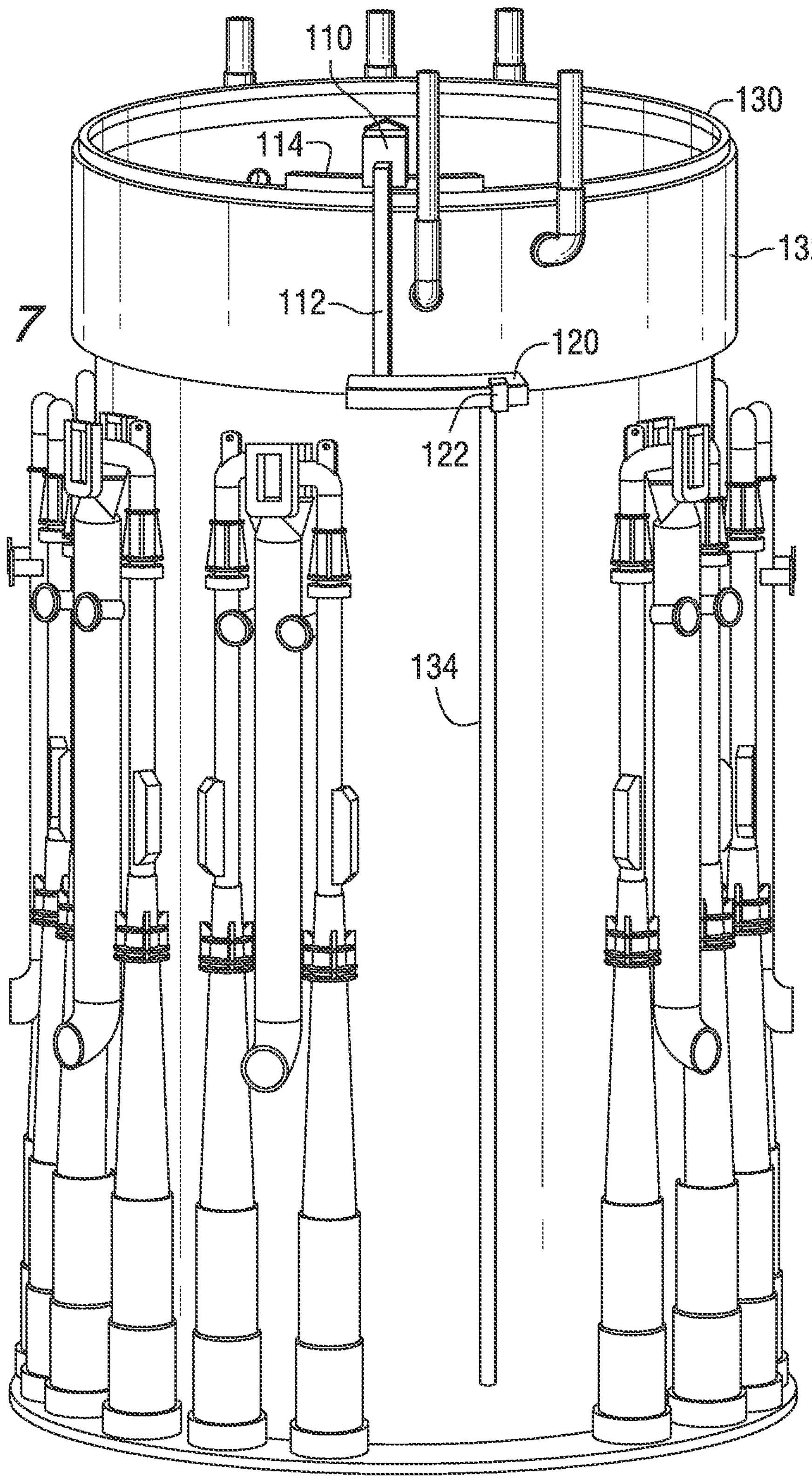


FIG. 6D

FIG. 7



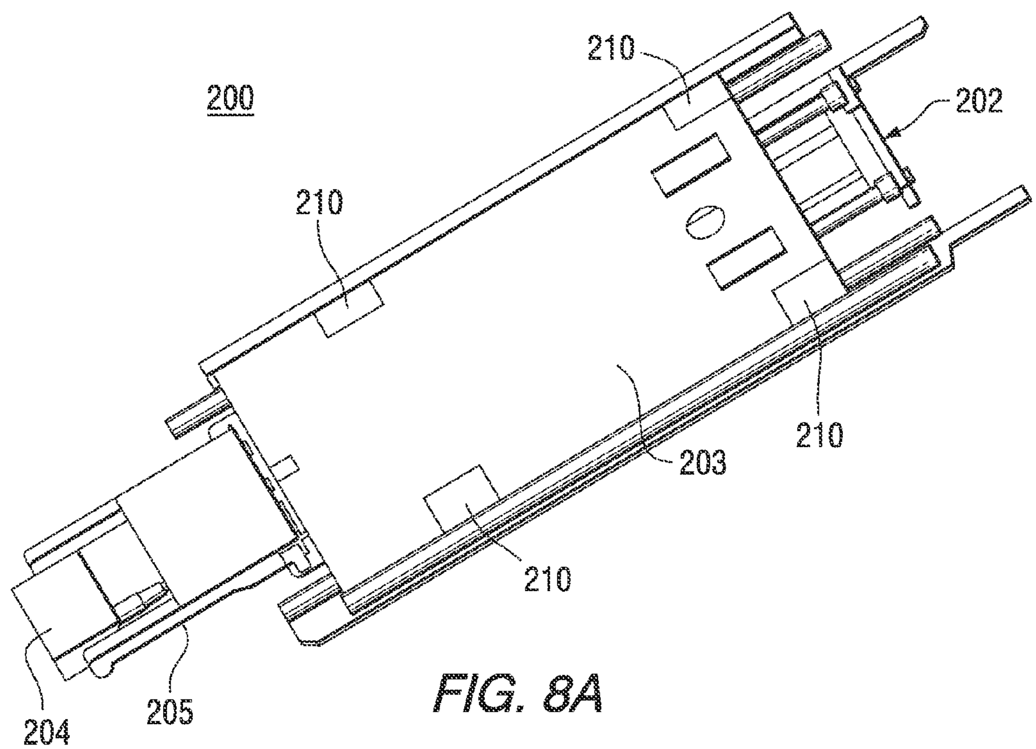


FIG. 8A

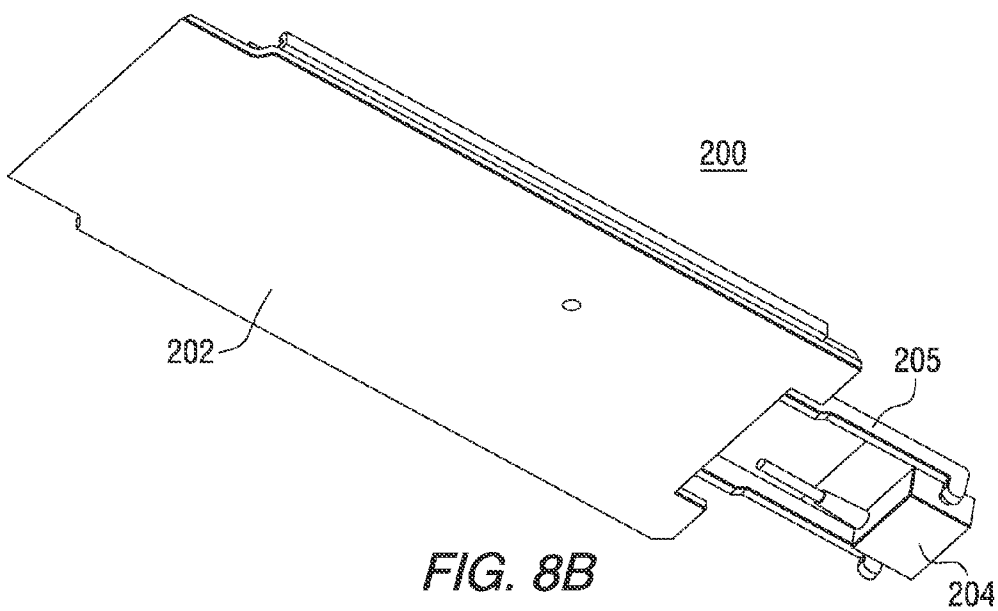


FIG. 8B

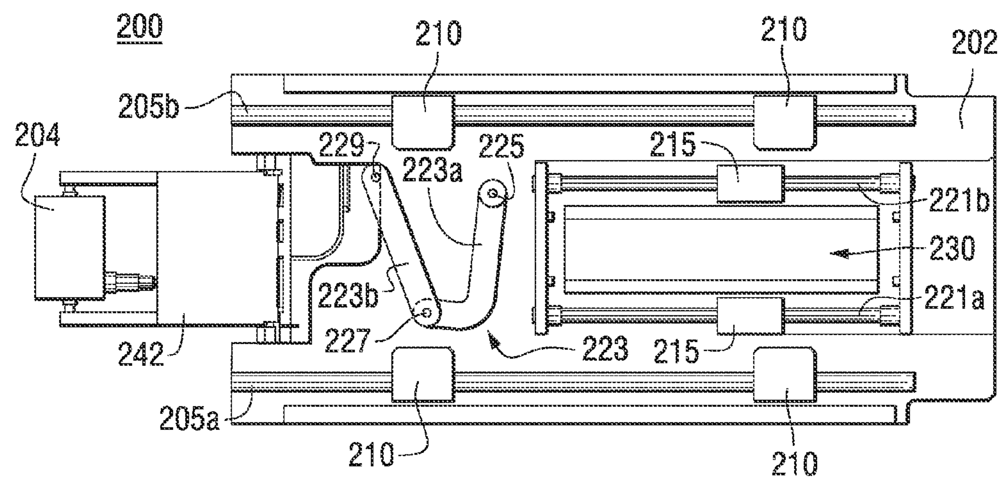


FIG. 9

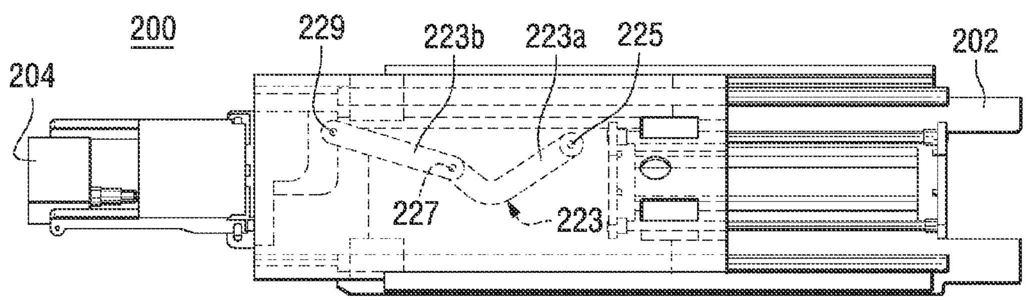


FIG. 10A

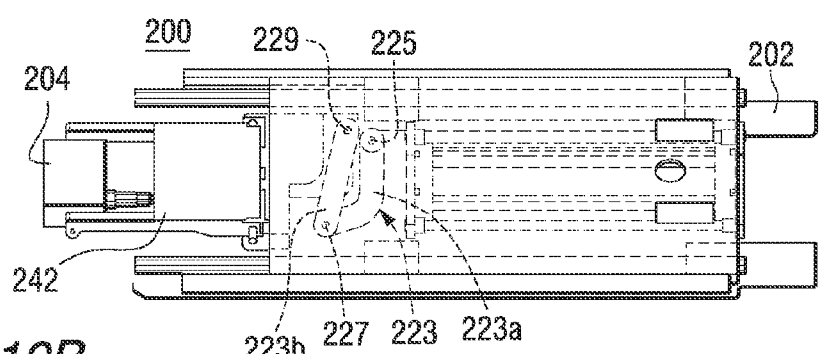


FIG. 10B

APPARATUS AND METHOD TO CONTROL SENSOR POSITION IN LIMITED ACCESS AREAS WITHIN A NUCLEAR REACTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. Section 119(e) from Provisional Application 61/711,239, entitled "Apparatus and Method to Control Sensor Position in Limited Access Areas Within a Nuclear Reactor" filed on Oct. 9, 2012.

FIELD OF THE INVENTION

This invention generally concerns robotic systems and is specifically concerned with an improved apparatus and method for remotely positioning a sensor, such as an ultrasonic probe, in limited access areas within a nuclear reactor.

BACKGROUND OF THE INVENTION

A nuclear reactor produces electrical power by heating water in a reactor pressure vessel that contains a nuclear fuel core in order to generate steam which is used in turn to drive a steam turbine. Various components and structures in a nuclear reactor are examined periodically assess its structural integrity and determine the need for repair. Ultrasonic inspection is a known technique for detecting cracks in nuclear reactor components. The inspection areas in the nuclear reactor may have limited access and therefore, difficult to assess using an inspection tool. For example, the core shroud welds are periodically assessed for stress corrosion cracking. The presence of stress corrosion cracking can diminish the structural integrity of the core shroud. However, the core shroud is difficult to access. Installation access is limited to the annular space between the outside of the shroud and the inside of the reactor pressure vessel, between adjacent jet pumps. Scanning operation access is additionally restricted within the narrow space between the shroud and jet pumps.

Further, the inspection areas in a nuclear reactor can be highly radioactive and can pose safety risks for personnel working in these areas. Thus, inspection of these areas for the most part can require a robotic device which can be installed remotely and operated within the narrowly restricted space.

Inspecting and repairing nuclear reactors, such as boiling water reactors, typically consist of manually controlled poles and ropes to manipulate servicing devices and/or positioning of these devices. During reactor shut down, servicing of some components require installation of inspection manipulators or devices 30 to 100 feet deep within reactor coolant. Relatively long durations are required to install or remove manipulators and can impact the plant shutdown duration. In addition, different inspection scopes can require several manipulator reconfigurations requiring additional manipulator installations and removals. The long durations cannot only impact plant shutdown durations, but also increase personnel radiation and contamination exposure.

Plant utilities have a desire to reduce the number of manipulator installations and removals to reduce radiological exposure as well as cost and plant outage impact. This invention allows the number of reconfigurations, installations and removals to be minimized. It is contemplated that if utilized on currently available manipulators, approximately one-half of the configurations may be eliminated.

SUMMARY OF THE INVENTION

The invention provides apparatus and methods for inspecting a core shroud in a reactor vessel. In one aspect, the invention provides an apparatus for remotely positioning a sensor in an area of a nuclear reactor. The apparatus includes a bottom frame, a top cover having a first end and a second end, the top cover substantially aligned with the bottom frame and positioned above the bottom frame, a sensor connected to the first end of the top cover, a first linear rail, a second linear rail substantially aligned in a parallel relationship to the first linear rail, a mechanism movably connected to each of the first and second linear rails and connected to the top cover, wherein the mechanism is effective to horizontally move the top cover relative to the bottom frame, and at least one cable having a first end and a second end, the first end being connected to the sensor and a second end being connected to a power source, signal source or receiver.

The apparatus can further include a protective cover connected to the bottom frame and effective to house a portion of the cable. The apparatus can also further include a two bar linkage system including a first bar having a first end and a second end, a second bar having a first end and a second end, the first end of the first bar connected to a pin which is attached to the bottom frame, the second end of the first bar connected to a pivot pin, the first end of the second bar connected to a pin which is attached to the top cover, and the second end of the second bar connected to the pivot pin, wherein when the top cover is moved horizontally the two bar linkage system is in an extended position.

In the apparatus, the first end of the top cover can have an access hole positioned therein to interface with a manual pick device to extend or retract the apparatus. The apparatus can further include at least two hydraulic cylinders at least partially attached to the top cover to horizontally drive the top cover from a first position to a second position to extend the sensor from a first position to a second position.

The cable can extend from the sensor through the two bar linkage system such that the linkage system protects the cable.

The first end of the top cover can be connected to an arm of an inspection tool and the sensor can be effective to inspect a component in a nuclear reactor. In certain embodiments, the component is a core shroud in a reactor pressure vessel. The tool can be positioned on the core shroud and the apparatus can be positioned in an annulus formed between the core shroud and a wall of the reactor pressure vessel.

In another aspect, the invention provides a method for remotely positioning a sensor in an area of a nuclear reactor. The method includes obtaining a sensor positioning apparatus including a bottom frame, a top cover having a first end and a second end, the top cover substantially aligned with the bottom frame and positioned above the bottom frame, a sensor connected to the first end of the top cover, a first linear rail, a second linear rail substantially aligned in a parallel relationship to the first linear rail, a mechanism movably connected to each of the first and second linear rails and connected to the top cover, wherein the mechanism is effective to horizontally move the top cover relative to the bottom frame, and at least one cable having a first end and a second end, the first end being connected to the sensor and a second end being connected to a power source, signal source or receiver, and connecting the sensor positioning apparatus to an inspection tool.

In another aspect, the apparatus of the invention is used to position a sensor attached thereto to a specific location relative to a sensor that is attached to an inspection tool.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the invention can be gained from the following description of the preferred embodiments when read in conjunction with the accompanying drawings in which:

FIG. **1**A is a schematic showing an elevational view of pertinent portions of a conventional BWR;

FIG. **1**B is a sectional view of a portion of the core shroud incorporated in the BWR depicted in FIG. **1**A;

FIG. **2** is a front view of a core shroud inspecting apparatus, in accordance with certain embodiments of the invention;

FIG. **3** is a perspective view of the core shroud inspecting apparatus of FIG. **2** showing a fixed gear rack mechanism, in accordance with certain embodiments of the invention;

FIG. **4** is a perspective view of the core shroud inspecting apparatus of FIG. **2** showing a movable bearing system, in accordance with certain embodiments of the invention;

FIG. **5** is a detailed view of the lower track of the core shroud inspecting apparatus of FIG. **2**, in accordance with certain embodiments of the invention;

FIGS. **6**A through **6**D are detailed views of the precision positioners for the end effectors of the core shroud inspecting apparatus of FIG. **2**, in accordance with certain embodiments of the invention;

FIG. **7** is a front view of the core shroud inspecting apparatus of FIG. **2** installed on a core shroud of a nuclear reactor with a sensor positioning apparatus attached thereto, in accordance with certain embodiments of the invention;

FIG. **8**A is a perspective view and **8**B is a bottom view of a sensor positioning apparatus, in accordance with certain embodiments of the invention;

FIG. **9** is a top view of the sensor positioning apparatus of FIG. **8**A with the top cover removed, in accordance with certain embodiments of the invention; and

FIGS. **10**A and **10**B are top views of the sensor positioning apparatus of FIG. **9** with the top cover removed; FIG. **10**A shows the sensor and two bar linkage in an extended configuration, in accordance with certain embodiments of the invention; and FIG. **10**B shows the sensor and two bar linkage in a contracted configuration, in accordance with certain embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. There terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and similarly, a second element could be termed a first element, without departing from the scope of the embodiments. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

It should be understood that when an element of component is referred to as being "on", "connected to," "coupled to," or "covering" another element or layer, it may be directly on, connected to, coupled to, or covering the other element or layer or intervening elements or components may be present.

Spatially relative terms (e.g., "beneath," "below," "lower," "above," "upper," and the like) may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It should be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the term "below" may encompass both an orientation of above and below. The device may be otherwise oriented (rotated **90** degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

The singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes" and/or "including," when used herein, specify the presence of stated features, integers, steps, operations, elements and/or components, but do not preclude the present or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

The invention relates to robotic devices for remotely positioning a sensor, such as an ultrasonic probe, in limited access areas within a nuclear reactor. The sensor can be employed to inspect or repair components and structures in the nuclear reactor which have limited access for the introduction and installation of an inspection or repair tool. In certain embodiments, these sensors are suitable for use in inspecting the core shroud of a nuclear reactor wherein the sensor is positioned in the narrow annulus formed between the core shroud and the wall of the reactor pressure vessel.

The invention can be used in light water nuclear reactors, such as boiling water reactors and pressurized water reactors.

The apparatus in accordance with certain embodiments of the invention generally is connected to a tool employed to inspect components and structures in a nuclear reactor and particularly those having limited access. In certain embodiments, the apparatus of the invention is connected to a tool for inspecting a core shroud in a reactor pressure vessel of a nuclear reactor. Typically, this inspection is conducted by positioning an inspection tool on the core shroud. The inspection tool includes an arm which extends vertically along the core shroud in an annulus space formed between the core shroud and the wall of the reactor pressure vessel. The arm and a sensor connected thereto are operable to move vertically and circumferentially along the core shroud to inspect the surface and welds contained therein. In certain embodiments, the apparatus of this invention is connected to a lower end of the arm to extend the vertical distance of the sensor along the core shroud. Further, the apparatus of the invention provides a means of protecting the cable through which power and signals are provided to the sensor. Moreover, the apparatus of the invention is operable hydraulically or pneumatically without the need for providing electrical wires.

The use of the apparatus of the invention will be described with regard to the inspection of a core shroud using a particular inspection tool. However, it is to be understood that the apparatus of the invention can be applied to inspecting, modifying and repairing procedures performed on a wide variety of components and structures in a nuclear reactor and the apparatus of the invention can be connected to various inspection tools that may be used to perform the inspections, modifications and repairs.

Referring to FIG. **1**A, there is illustrated a core shroud **2** in a reactor pressure vessel (RPV) **4** of a conventional boiling water reactor (BWR). Feedwater is admitted into the RPV **4** via a feedwater inlet (not shown) and a feedwater sparger **6**, which is a ring-shaped pipe having suitable apertures for circumferentially distributing the feedwater inside the RPV **4**. The feedwater from the sparger **6** flows downwardly through a downcomer annulus **8**, which is an annular region formed between the core shroud **2** and the RPV **4**.

The core shroud **2** is a stainless steel cylinder surrounding the nuclear fuel core, the location of which is generally designated by numeral **10** in FIG. **1**. The core is made up of a plurality of fuel bundle assemblies (not shown). Each array of fuel bundle assemblies is supported at the top by a top guide and at the bottom by a core plate (neither of which are shown). The core top guide provides lateral support for the top of the fuel assemblies and maintains the correct fuel channel spacing to permit control rod insertion.

The feedwater flows through the downcomer annulus **8**, into jet pumps **18**, and into the core lower plenum **12**. The feedwater subsequently enters the fuel assemblies, wherein a boiling boundary layer is established. A mixture of water and steam enters a core upper plenum **14** under a shroud head **16**. The steam-water mixture than flows through vertical standpipes (not shown) atop the shroud head **16** and enters steam separators (not shown), which separate liquid water from steam. The liquid water then mixes with feedwater in the mixing plenum, which mixture then returns to the reactor core via the downcomer annulus **8**. The steam is withdrawn from the RPV via a steam outlet.

The BWR also includes a coolant recirculation system which provides the forced convection flow through the core which is necessary to attain the required power density. A portion of the water is removed from the lower end of the downcomer annulus **8** via a recirculation water outlet (not visible in FIG. **1**) and forced by a centrifugal recirculation pump (not shown) into jet pump assemblies **18** (two of which are shown in FIG. **1**A) via recirculation water inlets **20**. The BWR has two recirculation pumps, each of which provides the driving flow for a plurality of jet pump assemblies. The jet pump assemblies are circumferentially distributed around the core shroud **2**.

Referring to FIG. **1**B, there is illustrated the core shroud **2** in detail. There is a shroud head flange **2***a* for supporting the shroud head **16**, a circular cylindrical upper shroud wall **2***b* having a top end welded to shroud head flange **2***a*, an annular top guide support ring **2***c* welded to the bottom end of the upper shroud wall **2***b*, a circular cylindrical middle shroud wall having a top end welded to top guide support ring **2***c* and consisting of upper and lower shell sections **2***d* and **2***e* joined by mid-shroud attachment weld, and an annular core plate support ring **2***f* welded to the bottom end of the middle shroud wall and to the top end of a lower shroud wall **2***g*. The entire shroud is supported by a shroud support **22**, which is welded to the bottom of lower shroud wall **2***g*, and by annular jet pump support plate **24**, which is welded at its inner diameter to shroud support **22** and at its outer diameter to RPV **4**.

The material of the shroud and associated welds is austenitic stainless steel having reduced carbon content. The heat-affected zones of the shroud girth welds, including the mid-shroud attachment weld, have residual weld stresses. Therefore, the mechanisms are present for mid-shroud attachment weld W and other girth welds to be susceptible to stress corrosion cracking.

An inspection tool is in contact with the core shroud and remotely operated in the annulus formed between the reactor pressure vessel and the core shroud to perform an inspection of the core shroud and any welds associated therewith. The tool includes an upper partial track which is positioned, e.g., placed on or connected to, a portion of the core shroud, such as an upper annular rim of the core shroud. In one embodiment, the upper partial track is placed on the steam dam of the core shroud and is supported thereon by its center of gravity. The upper partial track guides a precision head and rigid frame structure which is movably coupled to the upper partial track. The rigid frame structure extends vertically downward from the precision head. The precision head and frame structure includes an electric motor and ball bearings or the like which allows the structure to travel horizontally along the upper partial track. Further, the upper track contains motors and brakes which are systemically configured to allow the use of this apparatus without a complete track ring. The head and frame structure houses a sensor positioner for performing inspections or repairs on upper barrel regions of the core shroud. The precision head and frame are also operable to position a moveable lower track. The lower track region houses a lower arm and positioner to perform inspections or repairs on middle and lower reactor core shroud barrel regions. The positioner is a two-axis positioner which allows displacement of the arm vertically and circumferentially along the core shroud. At least one sensor, such as an ultrasonic transducer, is connected to the lower arm for inspecting the core shroud. In certain embodiments, the lower arm can include multiple sensors in a spaced apart relationship to each other.

Referring to FIG. **2**, there is illustrated a core shroud inspecting tool generally referred to by reference character **100** for inspecting a core shroud in a nuclear reactor, in accordance with certain embodiments of the invention. The apparatus **100** includes a head **110**, a frame **112** and a partial upper track **114**. The frame **112** has an upper end **116** and an opposite lower end **118**. The upper end **116** of the frame **112** is mounted to the head **110**. The head **110** is connected to the partial upper track **114** for suitably moving in a horizontal direction relative to the partial upper track **114**. The lower end **118** of the frame **112** is mounted to a lower track **120** for suitably moving the lower track **120** relative to the frame **112**. A carriage **122** is coupled to the lower track **120** for suitably moving horizontally relative to the lower track **120**. In certain embodiments, the partial upper track **114** and the lower track **120** are curved to suitably conform to the cylindrical shape of the core shroud in the nuclear reactor.

The partial upper track **114** includes a track brake system **124**. When the track brake system **124** is activated, the partial upper track **114** remains stationary and the head **110** (and frame **112** mounted thereto) is horizontally movable along the partial upper track **114**. When the track brake system **124** is deactivated or released, the partial upper track **114** can be driven into a different position along the rim of the core shroud. The track brake system **124** allows the head **110** and frame **112** to walk along the shroud without requiring a complete guide track ring. Thus, the head **110** and frame **112** are horizontally movable to drive along the partial upper track **114**, or alternatively, the partial upper track **114** is horizontally movable to be driven into a different position along the rim of the core shroud.

Referring to FIG. **3**, there is illustrated a fixed gear rack mechanism **150** for moving the partial upper track **114** along the core shroud. The fixed gear rack mechanism **150** interfaces with a positioning motor **155** and gear combination **157** located within the head **110**. When the motor **155** is driven, the head **110** is moved relative to the partial upper track **114**. If the track brake system **124** is applied, the partial upper track **114** will remain stationary relative to the core shroud and the head **110** moves relative to the partial upper track **114** and the core shroud. Alternatively, a positioning pin **160** can be pneumatically or hydraulically extended from the head **110** to react with reactor hardware positioned on the rim of the core shroud. If the position pin **160** is extended and the track brake system **124** is released, the head **110** remains stationary relative to the core shroud and the partial upper track will move relative to the core shroud. This provides for relocation of the entire apparatus **100** relative to the core shroud. The head motor **155** provides full position feedback so that global positioning of the entire apparatus is maintained and monitored within a tight tolerance.

Referring to FIG. **4**, there is illustrated a movable bearing system **170** which allows the lower track **120** to be driven relative to the frame **112** and to reach positions along the core shroud which are outside of the typical boundaries and obstructions exhibited by known apparatus. The frame **112** contains bearing wheels **172** that roll along guides **174** coupled to the lower track **120**.

Referring to FIGS. **4** and **5**, the frame **112** houses a fixed motor **175** and pinion gear **177** which can be driven and react against a rack gear **178** coupled to the lower track **120**. Upon rotation of the frame motor **175**, the lower track **120** moves relative to the frame **112**.

As shown in FIG. **5** and FIGS. **6**A-**6**D, the lower track **120** houses additional vertical and horizontal precision positioners **180** to provide precision position of tooling sensors or end effectors **182**. The carriage system **122** on the lower track **120** houses two motor/gear combinations **184**A,B and one pneumatic/hydraulic cylinder **185**. One of the motor/gear combinations **184**A interfaces with the rack gear **200** coupled to the lower track **120** which allows the carriage system **122** to move along the lower track **120**. The other motor/gear combination **184**B is coupled to a linear lead screw **190** which drives the pivoting cylinder **185** vertically in the general areas relative to the lower track **120**. The pivoting cylinder **185** provides pivoting motion for the attached arm **134** and end effectors **182** for positioning the end effectors **182** away from reactor obstructions. Overall, the apparatus contains seventeen axes of motion to position sensor and end effectors **182** in an efficient method to minimize size, plant shutdown schedule impacts, and personnel radiological exposure, and to maximize end effector coverage on the reactor core shroud around obstructions.

Referring to FIG. **7**, there is illustrated the core shroud inspecting tool **100** (shown in FIG. **2**) which is positioned on an annular rim **130** of a core shroud **132**. The apparatus **100** extends vertically downward into an annulus space formed between the core shroud **132** and a reactor pressure vessel (not shown). FIG. **7** includes the head **110**, frame **112**, partial upper track **114**, lower track **120**, and the carriage **122** (as shown FIG. **2**). Further, FIG. **7** includes an arm **134** connected to the carriage **122** and extending vertically downward therefrom along the core shroud **132**, and a sensor positioning apparatus **140** in accordance with this invention, connected to the lower end of the arm **134**. The arm **134** can further include a sensor (not shown) attached thereto. This sensor and the sensor of the positioning apparatus **140** are capable to detect and analyze the material of the core shroud **132** including any welds contained therein. Suitable sensors

for use in this invention can include those devices, such as but not limited to ultrasonic transducers, which are known in the art for inspections. In certain embodiments, multiple sensors can be positioned in a spaced apart relationship to each other along a vertical length of the arm **134**. Placement, e.g., spacing, of the sensors can be determined by and correspond to specific areas of the core shroud **132** to be inspected, such as the middle and lower barrels (not shown). In FIG. **7**, the lower track **120** is offset from the head **110** and the frame **112**, and the carriage **122** with the arm **134** is offset from the lower track **120**.

Referring to FIGS. **8**A and **8**B, there is illustrated a sensor positioning apparatus generally referred to by reference character **200** for controlling the position of a sensor, in accordance with certain embodiments of the invention. FIG. **8**A is a perspective view of the apparatus **200** and FIG. **8**B is a bottom view of the apparatus **200**. As shown in FIG. **8**A, the apparatus **200** includes a bottom frame **202** and a top cover **203**. The top cover **203** is substantially aligned with and positioned above the bottom frame **202** in a spaced apart relationship such that there is a space or opening formed between the bottom frame **202** and the top cover **203**. FIG. **8**A also includes a sensor **204** which is connected to the top cover **203** by a gimbal assembly **205** and linear rail support bearings **210** (which are later described). The top cover **203** contains an access hole (not shown) on an end opposite the end to which the sensor **204** is connected, to interface with a manual pick device (not shown). The manual pick device is used to remotely extend or retract the apparatus (e.g., from a component or structure being inspected) in the case of apparatus failure during operation. The bottom frame **202** and the top cover **203** utilize a generally smooth solid finish to prevent snagging on components when locating the sensor positioning apparatus **200** around close proximity obstructions.

Referring to FIG. **9**, there is illustrated the apparatus **200** as shown in FIGS. **8**A and **8**B. FIG. **9** is a top view of the apparatus **200** with the top cover **203** (as shown in FIG. **8**A) removed. FIG. **9** includes the bottom frame **202** and the sensor **204** as shown in FIGS. **8**A and **8**B. FIG. **9** also includes a first linear rail **205***a* and a second linear rail **205***b* positioned parallel to each other, and fixedly attached to the bottom frame **202**. Linear rail support bearings **210** are horizontally movably connected to each of the first and second linear rails **205***a,b*, in a spaced apart relationship. Each of the linear rail support bearings **210** positioned on the first linear rail **205***a* are substantially aligned parallel to each of the linear rail support bearings **210** positioned on the second linear rail **205***b*. Each of the linear rail support bearings **210** are coupled to the top cover **203** (as shown in FIG. **8**A) such that when the top cover **203** is moved horizontally, the linear rail support bearings **210** travel in a corresponding horizontal direction along the first and second linear rails **205***a,b*. FIG. **9** shows two linear rail support bearings **210** on each of the first and second linear rails **205***a,b*. However, it is understood that one or more linear rail support bearings may be used. Since the sensor **204** is connected to the top cover **203** (as shown in FIG. **8**A), the linear rail support bearings **210** are also operable to guide the sensor **204** from a first position, e.g., closed position, to a second position, e.g., extended position (shown in phantom lines in FIG. **9**).

FIG. **9** also shows a rodless cylinder carriage **215** which includes two custom-machined hydraulic cylinders **221***a,b*. A portion of these cylinders **221***a,b* are attached to the top cover **203** (as shown in FIG. **8**A) and operable to drive the top cover **203** and the sensor **204** from a closed position to an extended position. In certain embodiments, the hydraulic cylinders **221***a,b* employed are sealed rodless cylinders with magnetically coupled cylinder carriages. Without intending to be bound by any particular theory, it is believed that the use of these cylinders provide at least one of the following three design advantages over conventional cylinders known in the art: (i) a slim profile for maximum access in limited access areas, (ii) magnetic coupling to provide fail safe operation during unplanned collisions (e.g., the cylinders will decouple upon contact with an obstruction), and (iii) sealed enclosure to eliminate dynamic sealing and associated reliability concerns with under water usage. The apparatus **200** can be controlled with hydraulic pumps and valves to move a precise amount of hydraulic fluid into the cylinders **221***a,b* which will lock the cylinders in position. In contrast to pneumatic clylinders, the use of hydraulics allows the apparatus **200** to position the sensor **207** in any fixed position from a closed to a fully extended position.

Further, shown in FIG. **9** is a two bar linkage **223** having a first bar **223***a* and a second bar **223***b*. One end of the first bar **223***a* is connected to a first pin **225** which is attached to the bottom frame **202**. The other end of the first bar **223***a* is connected to a pivot pin **227**. One end of the second bar **223***b* is connected to a second pin **229** which is attached to the upper cover **203**. The other end of the second bar **223***b* is connected to the pivot pin **227**.

Referring to FIGS. **10**A and **10**B, there is illustrated the apparatus **200** as shown in FIG. **9**. FIGS. **10**A and **10**B include the bottom frame **202**, sensor **204**, two bar linkage **223**, first bar **223***a*, second bar **223***b*, first pin **225**, pivot pin **227** and second pin **229**. FIG. **10**A shows the two bar linkage **223** in an extended configuration when the sensor **204** is in an extended position. FIG. **10**B shows the two bar linkage **223** in a compressed configuration when the sensor **204** is in a closed position.

Referring to FIG. **9**, a cable protective covering **230** is connected to the bottom frame **202** to provide protection of cables and/or tubing (not shown) from getting pinched in moving parts or plant obstructions. In certain embodiments, the cable is utilized for sensor signal and power passage. For example, cable (not shown) can be connected to the sensor **204** and extend underneath the protective plate **242** through the first and second bars **223***a,b* of the two bar linkage **223** and underneath the protective covering **230**. The cable (not shown) can be connected to the first and second bars **223***a,b* such that it is extended or contracted as the two bar linkage **223** extends and contracts in accordance with horizontal movement of the top cover **203** (as previously discussed herein and shown in FIGS. **10**A and **10**B). Thus, the two bar linkage **223** can serve the purpose of cable management to prevent extremely sensitive cable from getting pinched and provides a mechanism to maintain minimum bend radius of the cabling during actuation of the apparatus **200**.

In certain embodiments, the apparatus of the invention can be utilized to position a sensor relative to another sensor that is attached to an inspection tool. For example, for illustrative purposes, a sensor is at a fixed elevation on an inspection tool arm, e.g., 60 inches, the tool has 10 inches of stroke, there is one sensor attached to the middle of the arm and one sensor attached to the end of the arm. Thus, this setup can scan a weld from 30 to 40 inches and from 60 to 70 inches. Thus, if there are welds to be examined at 32 and 62 inches, for example, this setup is capable of performing the weld exams in parallel. However, if the welds were located at 32 and 63 inches, the weld examinations would have to be performed separately because the sensors are not in the exact same location relative to each weld. In this scenario, the inspection tool in combination with the apparatus of the invention can perform both examinations within the same tool setup. For example, a scan of 32 to 34 inches (i.e., 2 inch stroke is required for examination), then 63 to 65 inches can be performed. Installation of the apparatus of the invention on the inspection tool allows the separation between the sensors to be set to exactly 31 inches and the inspections could be performed at the same time. In an alternative setup, if the welds were at 38 and 70 inches, the inspection tool without the apparatus of the invention would have to be reconfigured to perform the examination, while the tool with this apparatus of the invention can perform the examinations at the same time without any tool reconfigurations.

While specific embodiments of the invention have been described in detail, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular embodiments disclosed are meant to be illustrative only and not limiting as to the scope of the invention which is to be given the full breadth of the appended claims and any and all equivalents thereof.

We claim:

1. A robotic apparatus for remotely positioning a sensor in a nuclear reactor, comprising:
- a sensor;
- a bottom frame;
- a top cover having a first end and an opposite second end, the sensor connected to the first end, the top cover positioned parallel to the bottom frame and spaced apart from the bottom frame;
- a first linear rail connected to the bottom frame;
- a second linear rail connected to the bottom frame, substantially aligned in a parallel relationship to the first linear rail and spaced apart from the first linear rail;
- a first linear rail support coupled to the top cover and movably connected to the first linear rail;
- a second linear rail support coupled to the top cover and movably connected to the second linear rail; and
- a plurality of hydraulic cylinders attached to the top cover and structured to drive and move the top cover a distance in a horizontal direction, thereby moving the sensor connected to the top cover an equivalent distance in the horizontal direction, relative to the bottom frame, and thereby moving in a horizontal direction the first and second linear rail supports, coupled to the top cover, relative to the first and second linear rails, respectively.

2. The apparatus of claim **1**, further comprising a two bar linkage system, the linkage system comprising:
- a first bar having a first end and a second end;
- a second bar having a first end and a second end;
- the first end of the first bar connected to a first pin which is attached to the bottom frame;
- the second end of the first bar connected to a pivot pin;
- the first end of the second bar connected to a second pin which is attached to the top cover; and
- the second end of the second bar connected to the pivot pin,
- wherein when the top cover is moved horizontally the two bar linkage system is in an extended position.

3. The apparatus of claim **1**, wherein the plurality of hydraulic cylinders comprises two hydraulic cylinders.

4. A system for inspection in a nuclear reactor, which comprises:

a reactor pressure vessel having a wall;

a core shroud having an annular rim;

an annulus formed between the core shroud and the wall of the reactor pressure vessel;

an inspection tool connected to the core shroud and positioned in the annulus, which comprises:

an upper portion of the inspection tool positioned on the annular rim of the core shroud;

an arm of the inspection tool coupled to the upper portion and extending vertically downward along the core shroud in the annulus; and

a robotic apparatus connected to the arm of the inspection tool, the robotic apparatus, which comprises:

a sensor;

a bottom frame;

a top cover having a first end and an opposite second end, the sensor connected to the first end, the top cover positioned parallel to the bottom frame and spaced apart from the bottom frame;

a first linear rail connected to the bottom frame;

a second linear rail connected to the bottom frame, substantially aligned in a parallel relationship to the first linear rail and spaced apart from the first linear rail;

a first linear rail support coupled to the top cover and movably connected to the first linear rail;

a second linear rail support coupled to the top cover and movably connected to the second linear rail; and

a plurality of hydraulic cylinders attached to the top cover and structured to drive and move the top cover a distance in a horizontal direction, thereby moving the sensor connected to the top cover an equivalent distance in the horizontal direction, relative to the bottom frame, and thereby moving in a horizontal direction the first and second linear rail supports, coupled to the top cover, relative to the first and second linear rails, respectively,

wherein, the sensor is effective to inspect a component in a nuclear reactor.

5. The system of claim 4, wherein the upper portion comprises a partial upper track positioned on the annular rim of the core shroud and horizontally movable along the rim.

6. The system of claim 5, wherein the inspection tool further comprises:

an assembly, which comprises:

a head movably connected to the partial upper track such that the head is horizontally movable along the partial upper track;

a lower track;

a frame having a first end and a second end, the first end being mounted to the head and the second end being connected to the lower track such that the lower track is horizontally movable along the core shroud;

a carriage movably connected to the lower track and having one end of the arm connected thereto and the other opposite end of the arm having connecting thereto the robotic apparatus, and extending vertically downward along the core shroud;

a first driving mechanism connected to the head and the partial upper track, and structured to drive the head along the partial upper track and to drive the partial upper track along the rim;

a second driving mechanism connected to the frame and structured to drive the lower track along the core shroud; and

a third driving mechanism connected to the carriage and structured to drive said carriage along the lower track; and

a track brake system connected to the partial upper track,

wherein, when the track brake system is activated, the partial upper track remains stationary and the head is movable along the partial upper track, and

wherein, when the track brake system is deactivated, the partial upper track can be driven into a different position along the annular rim of the core shroud.

7. The system of claim 6, wherein bearing wheels are attached to the frame such that the frame is horizontally movable along the lower track.

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